VOLUME 76 SEPARATE No. 29

Rochester Public Library
AUG
115 South Avenue
ROCHESTER N. Y.

PROCEEDINGS

AMERICAN SOCIETY
OF
CIVIL ENGINEERS

AUGUST, 1950

AMERICAN SOCIETY OF CIVIL ENGINEERS FOUNDED 1852

SEDIMENTATION STUDIES AT CONCHAS RESERVOIR IN NEW MEXICO

By D. C. Bondurant, Assoc. M. ASCE

HYDRAULICS DIVISION

Headquarters of the Society
33 W. 39th St.
New York 18, N.Y.

PRICE $0.50 PER COPY

r620.6

The Society is not responsible for any statement made or opinion expressed in its publications

---

Published at Prince and Lemon Streets, Lancaster, Pa., by the American Society of Civil Engineers. Editorial and General Offices at 33 West Thirty-ninth Street, New York 18, N. Y. Reprints from this publication may be made on condition that the full title of paper, name of author, page reference, and date of publication by the Society are given.

Copyright 1950 by the American Society of Civil Engineers

Printed in the United States of America

AMERICAN SOCIETY OF CIVIL ENGINEERS
Founded November 5, 1852
PAPERS

SEDIMENTATION STUDIES AT CONCHAS RESERVOIR IN NEW MEXICO

By D. C. Bondurant,[1] Assoc. M. ASCE

Synopsis

Sedimentation problems in reservoirs include not only the loss of storage but the distribution of storage loss in respect to the several functions of multiple purpose reservoirs and the possible damage resulting from aggradation above or degradation below the reservoir. Analytical procedures for the computation of anticipated form and extent of sediment deposits are not perfected; and there are, unfortunately, only meager published data available from existing reservoirs for comparative estimates. Data on the form, extent, and type of sediment deposits in the Conchas Reservoir are given together with a description of the reservoir, its use, and the contributing drainage.

Introduction

The Conchas Reservoir has provided an excellent subject for sedimentation studies inasmuch as the reservoir has remained at a relatively constant elevation since it first filled in 1941 and inasmuch as it has experienced four major floods since its completion in 1939. The constant water level has enabled observations of sedimentation without the disturbing influence of different water levels; and the floods have provided material for study. These data will also be valuable for correlation with future observations when the pool is expected to vary over a wide range of levels. Sediment accumulation has amounted to 24,000 acre-ft, about 80% of which is in delta formation and 20% of which is fairly evenly distributed along the reservoir bottom. An estimated 6,000 acre-ft to 15,000 acre-ft of sediment has been passed through the conduits and a total of 7,000 acre-ft of bed materials has been degraded from the river bed downstream.

The Conchas Dam and Reservoir Project was constructed by the Corps of Engineers, Department of the Army, on the South Canadian River in New Mexico, immediately below the confluence of the Conchas River and about 30

Note.—Written comments are invited for publication; the last discussion should be submitted by February 1, 1951.

[1] Head, Sedimentation Section, Missouri River Div., Corps of Engrs., Dept. of the Army, Omaha, Nebr.; formerly Head, Hydrology and Sediment Section, Albuquerque Dist., Corps of Engrs., Albuquerque, N. Mex.

miles northwest of Tucumcari, N. Mex. It is a dual purpose project for flood control and water conservation, with storage for each of these purposes allocated at separate levels. Certain space is to be maintained vacant and available for temporary flood storage at all times except during the course of a flood; whereas the conservation storage will be operated as requested by water users. Water stored in the conservation pool will be utilized primarily by the Tucumcari Irrigation Project of the Bureau of Reclamation.

Drainage Area

The total drainage area above the dam is 7,350 sq miles consisting of 3,420 sq miles of mountains, 2,840 sq miles of plateau, and 1,090 sq miles of plains. The South Canadian River drainage is predominantly from mountains and plateaus whereas the Conchas River drainage is predominantly from plains. The South Canadian River emerges from the mountains into the plateau near Raton, N. Mex., descending into a deep canyon section near Taylor Springs, N. Mex. The river continues in this canyon to a point about 10 miles below the dam where the canyon is succeeded by a narrow valley bounded by gravelly hills. This valley extends for about 20 miles until the river again cuts deeper into the plains formation to a depth of from 300 ft to 400 ft below the elevation of the great "Staked Plains" at the New Mexico-Texas state line some 100 miles below the dam. All major tributaries above the mouth of the Conchas River head in the mountains and join the parent river in the plateau—either by surface channels entering above Taylor Springs or through deep canyons becoming confluent to the canyon section of the South Canadian River. The principal tributary (the Conchas River) heads in the plateau, emerges almost immediately through a short canyon, and flows across the plain to join the South Canadian River via a short canyon in the reservoir area immediately upstream from the dam.

The mountains are typically steep and rocky with a general forest cover which retards erosion and aids in reducing the precipitant runoff to some extent. These mountains are apparently composed of sedimentary types of rock, although adjacent mountain formations are volcanic and there are many minor volcanic cones in the vicinity. The plateau has a gentle flat slope eastward. Approximately one half of the plateau, adjacent to the mountains, has a fairly deep soil cover with numerous depressions and very poorly defined runoff; and the other half has a thin soil cover with numerous rock outcrops deeply eroded into rocky canyons which debouch into the parent canyon of the South Canadian River. The plains have a pronounced slope, deeper and more finely textured soil cover, and definite drainage showing evidence of considerable erosion of both sheet and gully types.

Reservoir Observations

The reservoir lies in the canyon section, is long and narrow in dimension with steep walls, and is V-shaped with the dam forming the apex of the V and the South Canadian and Conchas rivers, respectively, forming the arms. It has a total capacity of 800,000 acre-ft, divided as shown in Col. 3, Table 1. The dam, with a maximum height of 235 ft above the foundation, consists of a con-

crete gravity section across the canyon with contiguous earth dikes and with a 3,000-ft concrete emergency spillway at the north end. The service spillway, which is uncontrolled except by dimension, is located in the concrete dam, as are conduits for sluicing and low flow regulation, a small irrigation outlet, and a penstock for hydroelectric operating power. The conduits (Table 2(*a*)) are placed a few feet above the original river bed elevation. The main irrigation headworks (Table 2(*b*)) are at El. 4148 at the top of the dead storage pool and near the south end of the south dike. The length of the reservoir is 23 miles up the Canadian arm and 13 miles up the Conchas arm. Characteristics of the drainage area are given in Table 3.

TABLE 1.—CAPACITY DATA, CONCHAS DAM AND RESERVOIR IN NEW MEXICO

Flow	Acre-feet
Average annual flow	200,000
Inflow from January 1, 1939, to July, 1943	2,000,000

Purpose	Elevation (ft)	Original capacity (acre-ft)	Surface area (sq miles)	Length of Pool (Miles)		Spill-way net length (ft)	Spillway capacity (cu ft per sec)
				Cana-dian	Con-chas		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dead storage	4050 to 4155	100,000	5.5	15.9	8.8	...	...
Conservation Storage (Crest of Service Spillway)— Water surface, El. 4218 / Water surface, El. 4230	4155 to 4201	300,000	16.0	19.6	11.8	300	75,000 / 182,000
Flood Control Surface (Crest of Emergency Splilway)— Water surface, El. 4218 / Water surface, El. 4230	4201 to 4218	200,000	21.7	21.7	13.1	3,000	0 / 478,000
Surcharge (maximum water surface)	4218 to 4230	200,000	25.5	23.0	13.8	...	...
Total		800,000					

The history of the reservoir from closure in 1939 through 1947 has included 2 years of exceptionally high flow, 3 years of normal flow, and 3 years of subnormal flow. Storage began behind the incompleted structure in the spring of 1939, rose slowly to El. 4147 in the fall of 1939 when the structure was essentially completed, and remained at this approximate level until March, 1941, when a minor flood raised the level to El. 4163. In April and May, 1941, a major flood filled the conservation pool and caused a maximum discharge of about 6,000 cu ft per sec over the spillway. Again in September, 1941, a moderately large flood caused a spill, followed by further spills from major floods in the spring and fall of 1942. Since 1942 the inflow has just about balanced losses and minor uses and the pool level has been relatively constant. The studies reported in this paper cover an operation period of 5 years from 1939 through 1944 in so far as actual surveys are concerned; but subsequent inflows have been insufficient to add appreciably to the sediment inflow. There is no adequate basis for comparing the observed period with probable frequency since the

skew factor involved in a probability study of a 35-year period was so high as to indicate that the study was worthless. In so far as the probability may be accepted, each of the 1942 floods was of a magnitude to be expected to be equaled or exceeded once in an average of 20 years. Since the other two floods were of intermediate magnitude and no other intermediate floods have been experienced, it is estimated that the period reported corresponds to a norm of about 10 years.

During the construction of the project, provision was made for sedimentation studies by the establishment of ranges which were surveyed prior to filling. These ranges were established by: (1) A hydrographic survey of the river 75 miles downstream from the dam and nearly 200 miles upstream; (2) an excellent topographic survey over the reservoir area; and (3) permanent monuments for future use. After the project was completed, the sediment ranges were resurveyed in October, 1940 (prior to any floods), in June, 1942 (subsequent to the first three floods experienced), and in October, 1942 (after the last of the floods). A further resurvey was made in October, 1944, and in 1943 the hydrographic traverse was relocated and resurveyed for a long enough distance to insure coverage of aggradation and degradation of the river. A program of chemical analyses of reservoir water, continued since 1939, may also offer aid in studies of sedimentation. To a limited extent the suspended sediment load has been sampled at river stations upstream from the reservoir; but such sampling is completely inadequate because the region is too inaccessible for regular visits and because it has been impossible to find observers living near by. Samples are obtained daily from the two rivers at stations some miles upstream from the reservoir; but the results as of 1948 do not include the period of experienced floods.

TABLE 2.—DIMENSIONS AND CAPACITY OF OUTLETS AT CONCHAS DAM IN NEW MEXICO

Purpose	Invert elevation (ft)	No.	Size (ft)	Capacity at El. 4201 (Cu Ft per Sec)	
				Each	Total
(1)	(2)	(3)	(4)	(5)	(6)
(a) Conduits					
Sluicing	4061.9	6	4 by 5	2,140	12,840
Regulating	4062.3	2	4	1,000	2,000
(b) Other Outlets					
Irrigation headworks	4148.0	1	11	...	...
Beell Ranch outlet	4151.25	1	1.5	...	...
Hydroelectric penstock	4129.0	1	2	...	...

Reservoir surveys were made by sounding along the established range lines, using a shallow, cone-shaped weight which had a reasonably rapid sinking rate

but which did not sink in loose sediment deposits. Soundings were located by stadia distance or by intersection angles, or both; and each section was tied to two or more range markers at each end of the range. All range markers were located by closed traverse when first established, or were tied to such traverse by third-order triangulation.

TABLE 3.—TOPOGRAPHY OF DRAINAGE AREA, CONCHAS RESERVOIR IN NEW MEXICO

Stream (1)	Slope[a] (ft per mile) (2)	Mountains (sq miles) (3)	Plateau (sq miles) (4)	Plains (sq miles) (5)	Total (sq miles) (6)
South Canadian River—					
Near Logan, N. Mex. (75 miles downstream)	4.1				
Below Conchas Dam	5.1				
Immediately upstream from Conchas Dam	5.6	3,420	2,640	249	6,309
Head of reservoir	10.0				
Near Garmes, N. Mex. (23 miles upstream)	11.0				
Conchas River—					
Immediately upstream from confluence	13.1				
Head of reservoir	13.1	0	200	841	1,041
At Variadero, N. Mex. (30 miles upstream)	17.8				
Total (sq miles)		3,420	2,840	1,090	7,350

[a] River slopes prior to construction.

As of October, 1944, the total accumulation of sediment in the reservoir was 24,000 acre-ft, 15% of which was in the Conchas arm and 85% of which was in the Canadian arm (Table 4). The Conchas River has been by far the larger contributor in regard to sediment per unit of area drained and sediment per unit of inflow although, with the exception of the first flood (April–May, 1941), both

TABLE 4.—RECORD OF SEDIMENT OBSERVATIONS, IN ACRE-FEET, AT CONCHAS RESERVOIR IN NEW MEXICO

Date of survey	Conchas arm	Canadian arm	Total	Total, Within Periods	
				Acre-feet	Period
(1)	(2)	(3)	(4)	(5)	(6)
May, 1940	800	600	1,400	1,400	Moderate inflow period ending in October, 1940
June, 1942	2,200	13,800	16,000	14,600	Period of first three floods
November, 1942	3,700	16,300	20,000	4,000	Flood of September, 1942
October, 1944	3,700	20,300	24,000	4,000	Moderate inflow period, November, 1942, to October, 1944
Total	(15%)	(85%)	(100%)	24,000	Total period

normal and flood inflows of the Conchas River have been much smaller than those of the Canadian River.

During the same period it is estimated that from 6,000 acre-ft to 15,000 acre-ft was passed through the conduits. This estimate is based on samples of

conduit discharge showing sediment content up to 5% by weight of total sample during the flood of September, 1942. Degradation below the dam is recognizable for a distance of more than 40 miles, with appreciable lowering of the profile for 20 miles and a total of 7,000 acre-ft of material removed. Maximum depth of degradation below the dam is about 10 ft to rock outcrops and armored bed. There has been no aggradation above the reservoir limits; but a well-defined top-set bed is present within the limits of the backwater influence of the experienced floods. A reasonable correlation of suspended sediments in the river upstream and downstream against the deposit sediments in the reservoir, or a comparison of sediments before and after operation, cannot be made. Observers for sampling were simply not available in this sparsely settled area and the distances and terrain made sampling by operating personnel impracticable. Table 5 shows comparative data on sedimentation in other reservoirs.

TABLE 5.—COMPARATIVE SEDIMENTATION DATA

Reservoir and period	Area drained (sq miles)	Years	Sedimentation Rate	
			Inflow[a]	Annual[b]
(1)	(2)	(3)	(4)	(5)
Elephant Butte, New Mexico—	26,312			
1916–1925		8.67	0.016	0.78
1925–1935		9.67	0.016	0.52
McMillan, New Mexico—	16,989			
1894–1915		21.42	0.006	0.11
1915–1932		17.00	0.001	0.02
Roosevelt, Arizona—	5,670			
1911–1925		14.00	0.009	1.25
1925–1935		10.00	0.001	0.14
Zuni, Arizona—	500			
1907–1922		15.7	0.033	1.26
1922–1927		5.8	0.023	0.47
1927–1932		4.7	0.0005	0.02
Conchas, New Mexico (1939–1943)—				
Conchas arm	1,041	3.75	0.021	0.87
Canadian arm	6,309	3.75	0.009	0.64

[a] Acre-feet of sediment per acre-feet of inflow. [b] Acre-feet of sediment per square mile per year.

The sediment beds in the reservoir show a fairly well-defined division into the typical categories of top-set, fore-set (or delta), and bottom-set beds—although the definition is much more apparent in the Canadian arm than in the Conchas arm. Fig. 1 shows the profile of the reservoir prior to construction and at the time of the 1944 survey. The top-set bed of the Canadian arm is sharply defined: It begins at the approximate location of the computed beginning of the backwater effect and intersects the fore-set bed at an elevation which is the maximum attained by the pool during the floods. The fore-set bed is equally well defined on both streams, with surface and face slopes that show little deviation throughout their length. The bottom-set bed, particularly in the Canadian arm, is notable for the even deposit throughout its length. Reservoir sections show that the surfaces of the top-set and fore-set deposits are approximately level across the section. The bottom deposits, on the other hand, show a tendency toward an even depth across the section despite the fact that they are always deeper in the deeper sections of the crossing. The narrow width and steep slopes of the reservoir wall make it difficult to define a tendency in this respect.

The variation in the lengths and slopes of the deposits in the two arms is apparent and is no doubt caused by the variation in the slopes of the river as well as by the magnitude of floods and quantity of material deposited. The slope of the river below the dam is 5.1 ft per mile. It increases progressively up

the Canadian River to 10.0 ft per mile at the head of the reservoir and 11.0 ft per mile near Garmes, N. Mex., 23 miles upstream (Table 3). The Conchas River is much steeper with a slope of 13.1 ft per mile immediately above the confluence. This slope is retained to the head of the reservoir—but it increases to 17.8 ft per mile at Variadero, N. Mex., 18 miles above the head of the reservoir. Computations indicate that the backwater effect on the Conchas River from the experienced floods would have been appreciable only during the first flood when the pool was at a low level; and the top-set bed on that river is accordingly not well defined. The ratio of river slope to slopes of the top and face of the delta does show a rough correlation between the two arms—3.85 and 0.59 on the Canadian River against 4.78 and 0.45 on the Conchas River. Since a high flow on the Conchas River would still retain an appreciable velocity when reaching the break of the delta, this relation may not be valid. The maximum depth of deposit in the Canadian River is 42 ft; and, in the Conchas River, 32 ft.

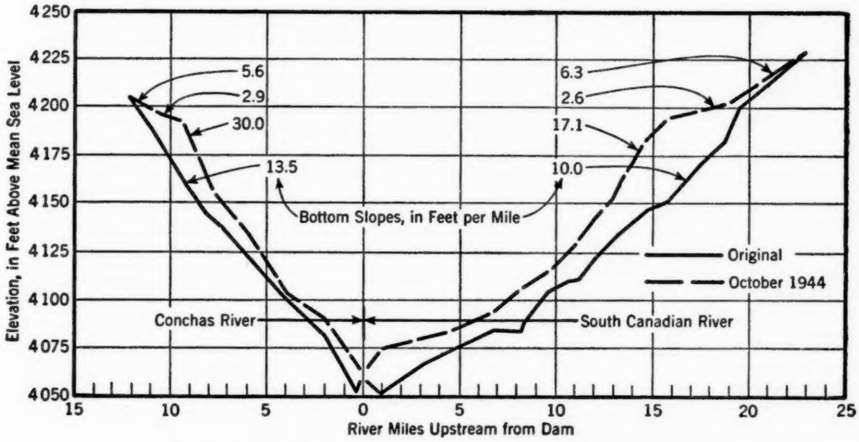

Fig. 1.—Bottom Profile Upstream from Conchas Reservoir

The bottom deposits contain somewhat less than 20% of the total accumulated sediment, and the longitudinal slope of these deposits appears to be almost completely a function of river slope with some tendency to level off in front of the dam. The sequence of pool level and flood magnitude indicates that the hump observable in the Conchas arm at mile 7 is actually the delta deposit of the flood of the spring of 1941. The bottom deposit is consolidated to the extent that a 16-lb sounding weight, dropped freely through the water, is stopped abruptly after penetrating a surface layer of soft material about 6 in. deep. The soft surface material will flow from an area about 2,000 yd in front of the dam when the conduits are opened; but, after this material has been removed, the flow becomes clear and soundings indicate that the material outside the 2,000-yd limit is undisturbed.

The grading of the material throughout the reservoir appears to be well defined according to location; but it will probably prove to be even better defined when sampling procedures can be improved. As of 1948, sampling of

material was restricted to surface samples except for one location at the lower end of the exposed delta of the Canadian arm where sampling was continued to a depth of 3 ft before the saturated material caved into the hole. Samples from exposed surfaces were obtained with a "cookie cutter," which is a cylinder about 4 in. in diameter by 4 in. deep, pushed into the sediment. The material around the sides is shoveled away, and a plate is inserted under the sampler. Volume was determined by cutting the material off even with the ends of the sampler and the sample was then placed in a bag for transportation to the laboratory.

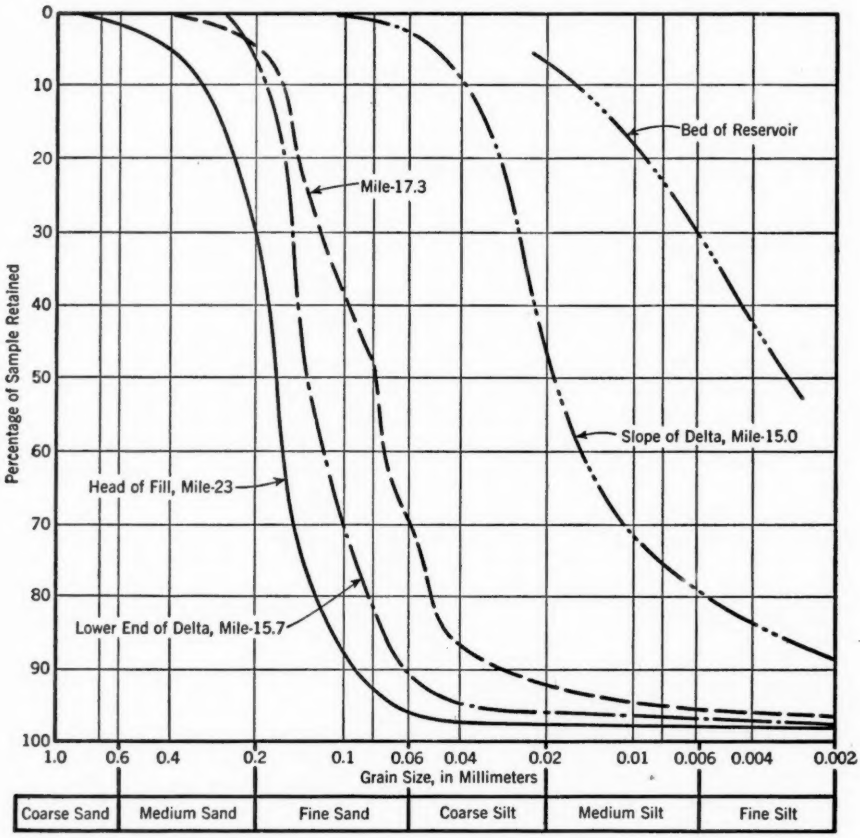

FIG. 2.—SAMPLES FROM CONCHAS RESERVOIR AT THE HEAD OF THE SOUTH CANADIAN ARM

Bottom samples were obtained by lowering a Foerst sampler to the bottom and tripping it after it penetrated the soft surface of the deposit. No density determinations could be made from the bottom samples, but the material was taken to the laboratory in a jar and was analyzed for particle size.

Fig. 2 shows the size analyses of samples from the surface at four locations extending from the lower end of the delta to the head of deposition. These analyses were made by the bottom withdrawal method. As might be expected,

the sizes of the materials increase progressively upstream and the range of sizes in individual samples is more restricted. All these samples probably contain some material deposited by wind and by low flows. The deeper samples at the lower end of the delta show a more coarse material, which is restricted to a limited size range and which shows little variation with depth after the first foot. The curve of grain sizes corresponds closely with the curve for mile 17.3, Fig. 2. The soft surface material from the bottom deposit appears to have consistent characteristics throughout the length of the deposit as shown in Fig. 3.

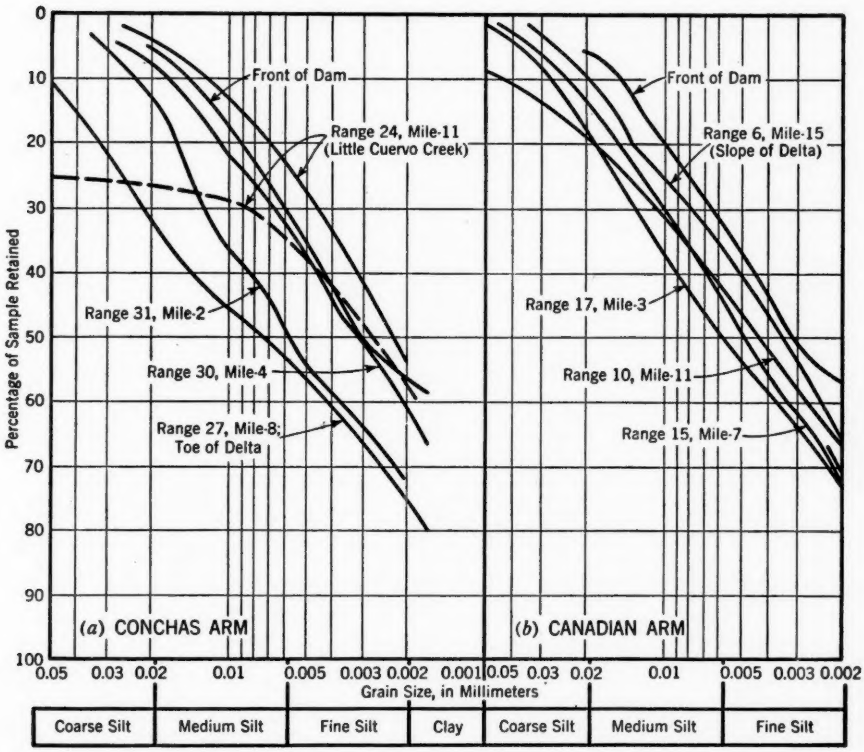

Fig. 3.—Sediment from the Conchas Reservoir, October, 1946

If the analyses of the delta samples are truly characteristic of the delta, they seem to show a very abrupt change in material type. Practically no material smaller than 30 microns is stopped in the delta and no material larger than 30 microns goes beyond the delta.

No density samples of the bottom beds have been obtained because of the lack of sampling equipment adequate for such sampling. The density of the delta samples, however, varies from 62 lb (dry weight) per cu ft at the surface to 86 lb (dry weight) per cu ft at a depth of 3 ft. These weights correspond closely to those obtained by the writer and C. S. Howard, Aff. ASCE, at John

Martin Reservoir on the Arkansas River in Colorado and at Alamogordo Reservoir on the Pecos River in New Mexico.

Although the deposits of the delta offer problems such as length, volume, and slope, investigations to date indicate that these deposits contain materials that may be fairly simply analyzed and which follow some regular law of transport and deposit. The materials of the bottom beds, when compared to those from a similar location in Lake Mead (Arizona-Nevada), indicate the presence of factors which are not fully explained and which may be important in the design of reservoirs. The deposit in front of Hoover Dam[2] is quite soft, with a density of 27 lb per cu ft at depths of as much as 50 ft below the surface of the deposit. Such a density is less than one half of the sediment content of samples of material that was flowing at a high velocity down the channel of Rio Puerco in New Mexico. (Samples taken by dipping a milk bottle in a flood on Rio Puerco have contained 68% (dry weight) of sediment.) In contrast to the soft deposit in Lake Mead, the deposit at Conchas Reservoir is firm enough to stop a 16-lb pear-shaped weight abruptly.

Since the variation in the character of the deposits at Lake Mead and at Conchas Reservoir was so great an extensive series of tests was made, running parallel tests with both Lake Mead sediment and Conchas sediment. The analyses were made by the bottom withdrawal tube method, with a few checks by the hydrometer method when the concentrations tested were adequate for the latter test. Each sediment was tested at various concentrations; each concentration was tested with Lake Mead water, Conchas water, and distilled water; and each water was used both with and without a deflocculating agent. In so far as these tests were concerned, the materials from the two sources did not show any differences that might indicate the reason for the variations in the natures of the deposit.

Summary

It may appear that the bottom-set materials have been given undue consideration; but the erratic behavior of these materials may evolve more questions in the design of a reservoir project than does the more regular behavior of the delta material. The precise location of the sediment deposits, and the effect on the allocation of storage to separate functions, have been highly important questions in at least one reservoir with which the writer is familiar. The volume occupied by sediment will be an important consideration in all reservoirs; and this volume may vary to a large degree, as is evidenced by the respective densities at Lake Mead and at Conchas reservoirs. The value of conduits for sluicing would vary with the type of deposit also, since material of the low density found at Lake Mead should flow readily whereas the Conchas material can be passed through the conduits only while it is moving as a density current. In addition, the behavior of fine sediments, when tested at high concentrations, indicates the possibility that a highly concentrated inflow might result in deposition at the reservoir head regardless of the size of the material. It is believed that this phase of reservoir sedimentation is worthy of more general study.

[2] "Stratified Flow in Reservoirs and Its Use in Prevention of Silting" by H. S. Bell, *Miscellaneous Publication No. 491*, U.S.D.A., Washington, D. C., 1942, p. 25, Fig. 25.

AMERICAN SOCIETY OF CIVIL ENGINEERS

OFFICERS FOR 1950

PRESIDENT
ERNEST E. HOWARD

VICE-PRESIDENTS

Term expires January, 1951:
HENRY J. SHERMAN
ROBERT B. BROOKS

Term expires January, 1952:
FRED C. SCOBEY
ALBERT HAERTLEIN

DIRECTORS

Term expires January, 1951:
WILLIAM M. GRIFFIN
KIRBY SMITH
FRANCIS S. FRIEL
JULIAN HINDS
WEBSTER L. BENHAM
C. GLENN CAPPEL

Term expires January, 1952:
WALDO G. BOWMAN
MORRIS GOODKIND
HAROLD L. BLAKESLEE
PAUL L. HOLLAND
EDMUND FRIEDMAN
S. T. HARDING

Term expires January, 1953:
OTTO HOLDEN
FRANK L. WEAVER
GORDON H. BUTLER
LOUIS R. HOWSON
G. BROOKS EARNEST
WALTER J. RYAN
GEORGE W. LAMB

PAST-PRESIDENTS
Members of the Board

R. E. DOUGHERTY
FRANKLIN THOMAS

TREASURER
CHARLES E. TROUT

EXECUTIVE SECRETARY
WILLIAM N. CAREY

ASSISTANT TREASURER
GEORGE W. BURPEE

ASSISTANT SECRETARY
E. L. CHANDLER

PROCEEDINGS OF THE SOCIETY

SYDNEY WILMOT
Manager of Technical Publications

HAROLD T. LARSEN
Editor of Technical Publications

COMMITTEE ON PUBLICATIONS
WALDO G. BOWMAN

FRANCIS S. FRIEL
S. T. HARDING
OTTO HOLDEN
LOUIS R. HOWSON
KIRBY SMITH